

# Morphological selection of teak (*Tectona grandis*) clones resistant to mistletoe infestation

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**Abstract.** Muttaqin Z, Nuh FN, Siregar IZ, Wibowo A, Rahayu S. 2025. Morphological selection of teak (*Tectona grandis*) clones resistant to mistletoe infestation. *Biodiversitas* 26: 4851-4864. Until now, study about the teak clones of Jati Plus Perhutani (JPP) resistance to mistletoe, which is very rarely of it in both Indonesia and other regions. The purpose of this study focuses on selecting teak clones with resistance to mistletoe by analyzing their morphological characters. In the study location at East Java, Indonesia, both the Clonal Seed Orchard (CSO) plot in Padangan, the JPP plot and the Seed Production Stand (SPS) plot in KPH Ngawi, the sample plot design follows the modified EFForTS/CRC990 guidelines. By contrast, the JPP plot utilizes the "tree pair method," where one stripe plot is free of mistletoe, whereas a paired stripe contains mistletoe. The parameters observed in related to the morphology of teak clones include 52 characters. Data analysis used the MVSP software, and Principal Component Analysis (PCA) to determine the significance of each morphological character based on the Eigenvalue and the percentage of variance of PCA. The phenogram results for CSO Padangan revealed five clusters have mixed both mistletoe-free and mistletoe-affected trees. The JPP plot exhibited two clusters with one cluster clearly consisted of teak trees without mistletoe. The SPS plot also displayed two clusters of only one cluster distinctly contained teak trees without mistletoe relatively. The key resistant teak clones identified were four morphological descriptors found mainly in the JPP plot showed a positive correlation: total height, number of branches, the leaf vein corners, the leaf base shape, the base of stem groove. Conversely, six characters exhibited a negative correlation: branch free height, petiole length, bark thickness, inner stem color, upper surface of the leaf, leaf flesh. Furthermore, it will be needed to test similarity some morphological descriptors significantly from the result of this study compare with of them of plants of tissue culture that taken of shoots superior teak clone.

**Keywords:** Mistletoe resistance, morphology characters, teak clone, *Tectona grandis*

## INTRODUCTION

Teak (*Tectona grandis*) is recognized as a major forestry species cultivated in tropical climates, including the monsoon forest formations of Java, Indonesia. Teak wood is classified as strong (class I) and durable (class II), exhibiting high durability and resilience against termites, fungi, and weather conditions, as well as good aesthetic qualities (Widiyatno et al. 2024). The teak clones that have received Protection of Plant Varieties (PPV) include Jati Plus Perhutani (JPP), namely PHT 1 and PHT 2. These varieties exhibit several superior traits, not only rapid growth, resistance to pest and disease disturbances, the ability to thrive in extreme environmental conditions, but also the capability to be harvested at 15 years of age, significantly shorter than the previous harvesting cycle of 70-90 years.

However, the teak plantation ecosystem has experienced several disturbances, including mistletoe attacks. Research conducted by Muttaqin et al. (2016a) indicates the emergence of mistletoe on clonal teak plants in the Clonal Seed Orchard (CSO) Padangan, Cepu, East

Java. Especially, for JPP PHT 1 and PHT 2, a total of 200,000 hectares has been planted across various regions such as West Java, Central Java, and East Java. However, these PHT 1 and II need testing for resistant and incidence values to mistletoe. Moreover, inconsistent growth has been observed due to various environmental factors, such as soil type, pest and disease attacks, and hemiparasitic mistletoe (Muttaqin et al. 2020). Another study conducted by Mulyadiana et al. (2020) demonstrated the existence of genetic variability in teak clones of Jati Unggul Nusantara (JUN) for early growth and location adaptation.

Field observations indicate that teak trees are heavily infested by the mistletoe species *Macrosolen tetragonus* and *Dendrophthoe pentandra*, which directly parasitizes teak hosts, along with *Viscum articulatum* exhibiting hyperparasitism. In CSO Padangan, the number of the teak clones infected was almost one third part of tree total were infected even founded a number of trees had experienced death. The mistletoe infestation in Perum Perhutani has spread widely in both area and distribution (Muttaqin et al. 2016a, et al. 2017; Rahayu et al. 2023). In another location, Solikin (2021) reported two mistletoe species found on

*Cassia fistula*, namely *D. pentandra* and *V. articulatum* in Purwodadi Botanic Garden, Pasuruan, East Java. Wahyuningsias et al. (2021) studied the diversity and distribution of mistletoes at Dramaga Campus, West Java, and noted the infestation of *D. pentandra* on teak tree branches. The economic impacts of mistletoe attacks include declined tree vigor and growth, reduced fruit and seed production, drying of branches, decreased log quality, and potential tree mortality (Mohan 2007). If left uncontrolled, mistletoe infestations can reduce the quality and quantity of wood, potentially killing the trees.

Thus, it is needed to study funding teak clones that are resistant to the mistletoe in the form of Protection of Plant Varieties (PPV), namely PHTn, and PHTn's have been generated before. Those processes consist of selection teak clones based on morphological descriptors, followed by the next study of molecular markers of microsatellite and Single-Nucleotide Polymorphism (SNP). This series of teak clone selection involves collecting shoots from parent trees based on their morphological characters. In the monsoon teak forests of Java, field observations indicate that although nearly all teak trees are susceptible to mistletoe, a few individual trees show signs of resistance. Currently, there has been no analysis of the relationship between teak clones using phenetic methods based on morphological characters. Previously, the leaf morphology of *D. pentandra*, *M. tetragonus*, and *V. articulatum* infesting teak clones in CSO Padangan was measured by Muttaqin et al. (2016b). This phenomenon is particularly interesting for breeding activities aimed at developing teak trees resistant to mistletoe.

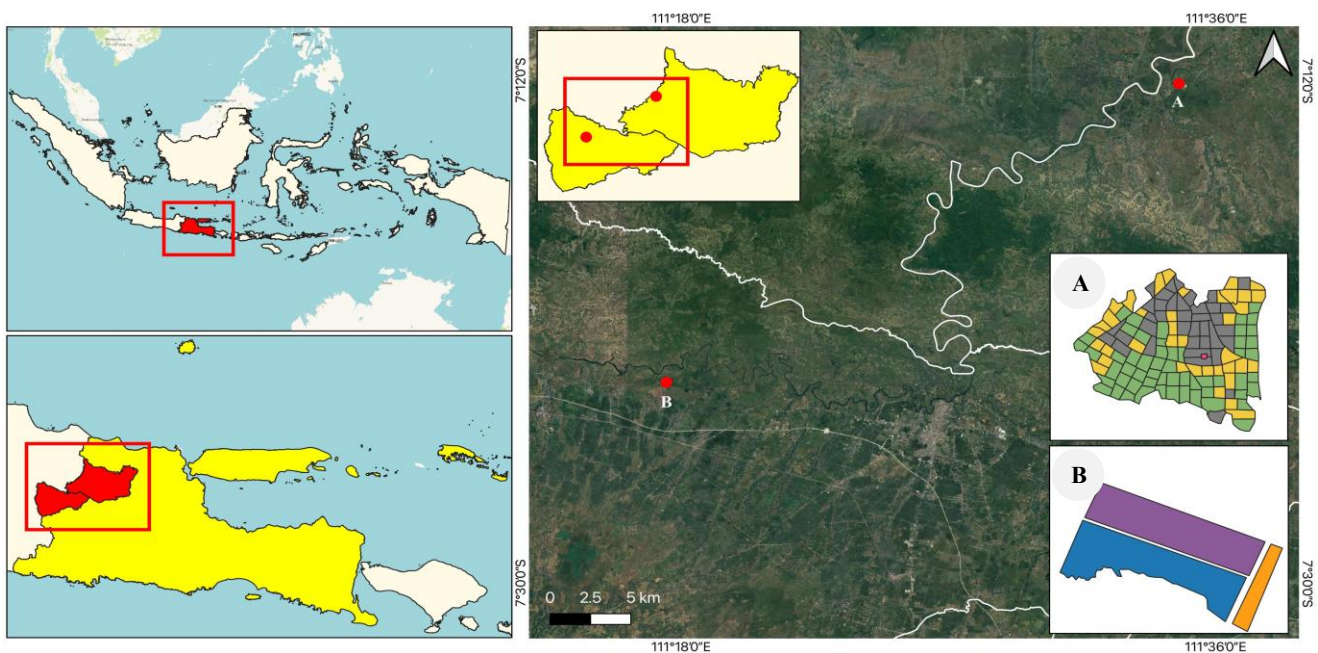
The urgency of this research on the selection of teak clones resistant to mistletoe is essential as a foundation for

an effective and efficient tree breeding program to produce resistant teak trees. This study aimed to identify teak clones with potential morphological resistance to mistletoe. It is expected that the novelty of the study, which provides early data available about some morphological traits, will help formulate trait descriptors for further genetic improvement and plant propagation programs; especially, teak clones resistant to mistletoe through the expected result of PHT1n and PHT2n.

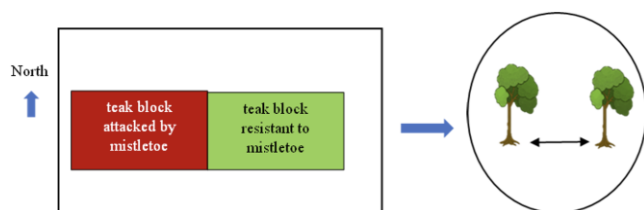
## MATERIALS AND METHODS

### Study area

The research was conducted directly in plantation sites where super teak clones were cultivated and teak plants located in the JPP plot in compartments 61A and 64E, which were planted in 2012, in RPH Sidolaju, BKPH Kedunggal, KPH Ngawi, Perhutani East Java Division, Indonesia (Figure 1). For comparison, a location of the Stand of Seed Production Stand (SPS), planted in 2004, near the JPP plot, was also examined. This area includes trees affected by mistletoe as well as those resistant to it in KPH Ngawi, and the Clonal Seed Orchard (CSO) in Padangan, Cepu, East Java, which consists of 144 teak clones. These clones originated from 100 superior teak trees spread out in Java Island and other places. Maps of the research plots and their layouts are presented in Figures 1 and 2. Sample determination in the JPP plot, SPS plot, and CSO plot is based on the "tree pair method" (Zhou et al. 2019; Xie et al. 2022), where trees affected by mistletoe are closely paired with trees that are not affected.



**Figure 1.** A Location of research in the Teak Clonal Seed Orchard (CSO) Padangan, Cepu, East Java, Indonesia (Muttaqin et al. 2016a, modified); B. JPP plot and Seed Production Stand (SPS), RPH Sidolaju, BKPH Kedunggal, KPH Ngawi, East Java (Widiyatno et al. 2024, modified)



**Figure 2.** Research layout in JPP plots (61A and 64E), Sidolaju Forest Management Sub Unit, Kedunggalar Forest Management Part, Ngawi Forest Management Unit, Perhutani East Java, Indonesia

## Procedures

### Sampling technique

In CSO Padangan, the sample unit is a Sample Observation Plot (SOP) measuring 50 m × 50 m, which is established using clonal teak planted at a spacing distance of 10 m by 10 m. SOP is a homogeneous stand unit designed based on several factors to standardize overall site conditions. These factors include the area of clonal teak stands infected by mistletoe at varying intensities (class 1: light, class 2: medium, class 3: heavy) and uniform environmental conditions around the site (e.g., microclimate type, soil type). Furthermore, the placement of SOPs does not need to be compact; they can be determined separately while still meeting specified criteria. Within each SOP, square-shaped Measurement Plots (MPs) measuring 50 m × 50 m were created in three replications for every intensity of mistletoe infestation, resulting in a total of nine SOPs. The selection of MPs within the SOP units refers to a list of MPs that meet the specified criteria and are randomly located within the CSO Padangan area. The design of the SOP and MP creation follows the EFForTS/CRC990 guidelines (Drescher et al. 2016), with no treatment applied to the MPs. The design is illustrated in Figure 3.

The sample unit in the form of SOP was also applied in the plot of the Seed Production Stand (SPS) planted in 2004. The difference is that the SOP is sized 25 m × 25 m, adjusted to a planting distance of 3 m × 3 m, with three SOPs established. The replications are three SOPs, each consisting of a plot with a mistletoe attack (low), of medium attack, and of hard attack. Another plot is in the JPP area, consisting of two paired rows, one row of the JPP plot and one row of teak plants from superior seeds sourced from CSO. The number of tree pairs is 20 sample trees, which also serve as 20 replications. Thus, every plot of CSO, JPP, SPS sites adjust of stand condition has the sum of replication differently.

### Data collection (measured parameters)

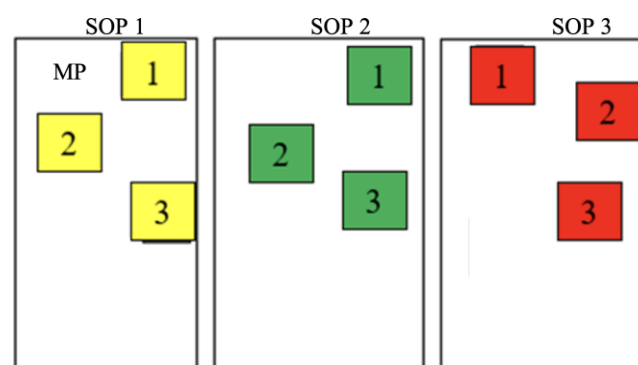
Data was collected using purposive sampling techniques on Observation Sample Plots (SOP) measuring 50 m × 50 m in CSO Padangan site. The SOP represents the intensity of mistletoe attacks at three levels: light infestation (≤8 trees with mistletoe), moderate infestation (9-18 trees of it), and heavy infestation (>18 trees of it) based on Muttaqin et al. (2016a). Each attack intensity is

replicated three times. The sampling technique for observing morphological characters at each SOP involves selecting two pairs of trees: one attacked by mistletoe and one not attacked by mistletoe. Similarly, the second site, in the JPP plot located in the compartment of 64E, RPH Sidolaju, BKPH Kedunggalar, KPH Ngawi, planting year 2012, and the SPS in the adjacent plot (61A). In the JPP plot, one pair of teak trees that are not infested with mistletoe (JPP) (no infestation: 0 tree) and infested with mistletoe (teak plant from seed of CSO) are determined as light infestation, located on two opposite plant rows. In the third site, in the SPS, PCP is placed with a procedure similar to CSO Padangan and there are 3 SOPs determined for infestation (light, moderate, and heavy).

Until now, there has been no early study about the morphology characters of teak clones, particularly in Perhutani (Java Island). So, the parameters observed in this study related to the morphology of teak trees include 52 characters selected measured qualitatively and quantitatively, primarily concerning branches, leaves, and trunks. While as comparison, Reategui-Betancourt et al. (2020, 2021) used 41 qualitative and quantitative characters for evaluation. In addition, Zhang et al. (2023) were using mistletoe leaf morphology traits such as Specific Leaf Area (SLA) and Leaf Dry Matter Content (LDMC).

For this study, morphological observations of trees were conducted by measuring their diameter and height, as well as the dimensions and shape of the crown/canopy. Tree diameter: The tree trunk diameter was measured at a height of 1.3 m from the ground or at breast height (dbh). Tree height: The height of the tree was measured with a Haga hypsometer by sighting at the tree from the base of the trunk at ground level to the top of the canopy, with a measurement distance of 20 m.

Dimensions and shape of the crown/canopy and (i) Detailed leaf morphology: leaf type, leaf length and width, leaf tip shape, leaf texture, leaf base and petiole, primary leaf veins, secondary vein types, and others; (ii) Detailed stem morphology: stem shape, bark texture and color, stem growth direction, main stem development, branch position and growth direction, and others (Liu et al. 2023).



**Figure 3.** Design of the SOP layout and the MPs within the SOP, following the modified EFForTS/CRC990 guidelines for this study. MP size: 50 m × 50 m. SOP 1: Intensity of class 1 mistletoe attack (low), SOP 2: Intensity of class 2 mistletoe attack (medium), SOP 3: Intensity of class 3 mistletoe attack (hard)

## Data analysis

### *Correlation analysis*

Morphological descriptors, due to their speed, simplicity, and cost-effectiveness, are commonly used to characterize and differentiate phenotypic diversity among individuals of the same species (Jingura and Kamusoko 2015; Suratman et al. 2016). In this study, we analyzed morphological character data, including parameters related to leaves, crown and stems, by utilizing the Multivariate Statistical Program (MVSP) software, version 3.22. Statistical analysis was conducted using the phenetic numerical classification method. All characterized and scored data were standardized to calculate the similarity index, resulting in values ranging from 0 to 1. Considering these data, the OTUs' similarity indices were computed using MVSP v.3.22 with the Jaccard coefficient formula to create a similarity matrix. A dendrogram was formed using the clustering method employing the Unweighted Pair Group Methods using Arithmetic averages (UPGMA) algorithm (Adiansyah et al. 2023). The similarity index was calculated using the Simple Matching Coefficient (SMC) formula based on morphological score data.

### *PCA Analysis different of ANOVA and regression*

Furthermore, principal component analysis or PCA was applied to identify the importance of each morphological character used (Purnomo and Khotimah 2019). The combination of cluster analysis and PCA aims to establish a fundamental empirical role of morphological characters in grouping accessions (Sari et al. 2016). In PCA, Eigenvalue indicates the amount of total data variation explained by each principal component. The larger the Eigenvalue, the more important and necessary that component is in explaining the data structure. This analysis is different from ANOVA and regression, in Eigenvalue, there is no direct hypothesis testing to produce a standard p-value or confidence interval, but there is a selection of criteria for the selection of major components based on Eigenvalue, such as Kaiser criteria, which is only components with Eigenvalue >1 as a threshold. Whereas, to calculate the percentage of variation for each PC = (PC Eigenvalue/total Eigenvalue of all PCs) x 100% (Hair et al. 2010; Jolliffe and Cadima 2016).

The key resistant teak clones identified significantly based on morphology characters were value (PC)<sub>n</sub> ≥ 3.50 for both correlation of positive and negative. The analysis culminated in a phenogram that vividly displays clusters of teak trees, with and without mistletoe infestation, based on their morphological characters, highlighting the practical implications of our findings for the field of botany and related studies.

## RESULTS AND DISCUSSION

### **Descriptions of Teak's morphological characters**

#### *Padangan's clonal seed orchard site*

Teak trees in CSO Padangan site exhibit a tree habitus with an obovate crown shape, where the main stem development is mostly monopodial, although some are

sympodial. The trunks are relatively straight, featuring a rough, peeling surface texture. The inner bark is brown, whereas the outer bark is pale yellowish. The stem fibers are predominantly straight, with some exhibiting wavy characteristics. The circumference of the teak trees in CSO Padangan ranges from 74.5 to 230 cm, corresponding to a diameter of 23.7 to 73.2 cm. The branches are rhythmically placed with a declinatus (drooping) growth direction. The leaf stalks have a semi-terete cross-section with marginal petiole attachment. Teak leaves have a petiole length of 0.5-4 cm and are classified as simple leaves with decussate arrangement, oval-opposite shape, and herbaceous texture.

The leaf tips of the CSO Padangan teak are pointed-rounded with a pointed base and feature symmetrical leaves. Teak leaves have a length of 7.3-46.0 cm and a width of 9.8-29.0 cm; young leaves are reddish-green, maturing to dark green. The upper leaf surface has a slightly hairy, smooth texture, while the underside is rough. The arrangement of the leaf veins is secondary, with angles smoothly decreasing proximally, and the veins are actinodromous, featuring a well-developed network and looped edge veins. The total height of teak trees in this location ranges from 12 to 30 m, with a branch-free height of 1.0-16.5 cm and a canopy density that varies from moderate to dense. This is supported by Hasnah et al. (2020), which states that teak trees can reach heights of 30-35 m in deep soil, with a clear trunk height of 10-20 m.

#### *Jati Plus Perhutani (JPP)'s site*

Teak trees in the JPP site also exhibit a tree habitus with an obovate, irregular crown and generally monopodial main stem development. Although most JPP teak trees have straight trunks, some individuals display bent trunks and multiple branches, with a surface texture that is mostly rough-flaky, with some smooth-flaky areas. The inner bark is brown, and the outer bark is gray. The stem fibers are straight, arranged rhythmically, with branches growing in a declinatus (drooping) direction. The leaf stalks have a semi-terete cross-section and marginal petiole attachment. The circumference of the teak trees in the JPP Plot ranges from 48 to 110 cm, corresponding to a diameter of 15.3-35.0 cm. The petiole lengths of teak leaves in this plot range from 0.25 to 3.50 cm.

Teak leaves are simple, with a decussate arrangement, oval-opposite shape, and herbaceous texture. The leaf tips in the JPP Plot taper to a rounded point with a sharp base, and the leaves are symmetrical. Teak leaves have lengths ranging from 16.0 to 61.2 cm and widths between 6.2 and 34.9 cm; young leaves are reddish-green, mature to light or dark green. The upper leaf surface varies in texture, ranging from slightly smooth to rough, while the underside is somewhat rough. The arrangement of the leaf veins features a secondary angle that smoothly decreases proximally, with actinodromous veins and a well-developed network, including looped edge veins. The total height of JPP teak trees ranges from 9 to 24 m, with a branch-free height of 1-15 cm and a canopy density that varies from sparse to dense.

### *The seed production stand (SPS) site*

Teak trees in the SPS site exhibit a tree habitus with an obovate, irregular crown and predominantly monopodial main stem development. SPS teak trees typically have straight trunks, though some individuals present bent trunks, wood eyes, and a branching surface texture that is mostly rough-flaking, with some smooth-flaking areas. The inner bark is brown, and the outer bark is gray. The stem fibers are straight, arranged rhythmically, with branches growing in a declinatus (drooping) direction. The leaf stalks have a semi-terete cross-section and marginal petiole attachment. The circumference of teak trees in SPS ranges from 49 to 143 cm, corresponding to a diameter of 15.6–45.5 cm. The leaves of SPS teak have petiole lengths ranging from 0.3 to 7.7 cm.

Teak leaves, with their simple structure and decussate arrangement, possess a unique charm. Their oval-opposite shape and herbaceous texture add to their distinctiveness. The rounded leaf tips of SPS teak, with a pointed base, and the symmetrical leaves further enhance their allure. Ranging from 16.0 to 47.2 cm in length and 9.4 to 27.3 cm in width, these leaves undergo a captivating transformation from reddish-green in their youth to a mature light or dark green. The upper leaf surface, with its varied texture, from somewhat smooth to rough, and the somewhat rough underside, add to their intriguing nature.

The arrangement of the leaf veins, with a secondary angle that smoothly decreases proximally, is a testament to the influence of environmental factors on teak growth. The actinodromous leaf veins, with a well-developed vein network and looped edge veins, further underscore this point. The total height of the teak in the stand of the seed production area, ranging from 10 to 15 m, with a branch-free height of 4 to 7 cm and a canopy density that varies from sparse to dense, is a result of these factors. It's a reminder of the crucial role that topography, ecological suitability, climate, land fertility (soil structure and texture), and the selection of quality seeds play in the growth of these magnificent trees. In addition, the importance of treatment and maintenance after planting cannot be overstated. As a comparison, the data of morphological characters of three sites were presented in the following Table 1, it shows the difference in value qualitatively and quantitatively of 29 morphology characters among three sites and teak clones that have mistletoe (B) and have no mistletoe (TB).

### **Phenogram of teak morphological characters**

A phenogram is a graphical representation that illustrates the taxonomic relationships among individuals or populations of teak based on observed morphological characters. It is usually constructed using data from various morphological traits such as leaf shape, stem size, flower structure, and seed characteristics. The use of phenograms can support tree breeding efforts. Observations of 52 parameters related to the morphological characters of teak trees, including leaf and stem. There were 29 parameters of morphology selected that different among of 3 site and between teak clone has no mistletoe and it has mistletoe. morphology, have been analyzed. The morphological

analysis of teak trees, both infested and not infested with mistletoe at the tree locations (CSO Padangan, JPP plot, and SPS plot), resulted in a phenogram or kinship tree presented in Figures 4, 6, and 8.

### *Phenogram of CSO Padangan's morphological characters*

The analysis results of the morphological characters phenogram for CSO Padangan are depicted in Figure 4. Figure 4 shows the results of a morphological analysis of pairs of CSO Padangan teak from 9 different plots. A total of 38 samples is divided into 5 clusters with Similarity Index Values (SIVs) ranging from 0.80 to 0.86 (80.0–86.0%). The level of dissimilarity is between 14.5% and 20.5%. Cluster I consists of 2 teak clone samples with an SIV of 0.80. These 2 trees exhibit different health conditions; one tree is healthy while the other one is infested with mistletoe. Despite their differing health conditions, the morphology of these 2 trees is quite similar, as evidenced by the relatively high SIV. Cluster I can be considered separate from the other clusters, which include clusters II, III, IV, and V, although cluster II is somewhat different from clusters III, IV, and V. Cluster II comprises 2 samples of teak clone trees. This cluster is affected by mistletoe, which may be due to influences from the mistletoe that are not morphologically apparent in the teak clones. Cluster II has an SIV of 0.805. Cluster III includes 16 teak clone tree samples. This cluster includes both trees with mistletoe and healthy trees. Cluster III has an SIV of 0.84, indicating that their morphological characters are very similar.

Cluster IV consists of 11 samples with an SIV of 0.86. Within Cluster IV, there are both healthy trees and those infested with mistletoe, indicating no significant morphological differences between the two groups. Cluster V comprises 7 samples of teak clone trees. Cluster V contains both healthy trees and trees with mistletoe infestation, with an SIV of 0.85. The 5 clusters formed from the CSO Padangan phenogram are all a mixture of healthy trees and those affected by mistletoe, but only Cluster I contains teak trees that are all infested with mistletoe. Therefore, it can be concluded that the morphological characters of teak clone trees do not specifically distinguish between healthy trees and those affected by mistletoe.

Generally, as shown in Figure 4, the dendrogram can be divided into two groups: the first group is Cluster I, and the second group includes clusters II, III, IV, and V. The scatter PCA case scores for CSO Padangan are presented in Figure 5. The clarity of the clearly identified function of each morphological character in the clustering of clone samples is clearly illustrated in that figure, showing not only direction but also the varying significance of each morphological character, represented as vectors with different lengths. In PCA (Figure 4), the distribution direction and the influence of the size of the morphological characters are indicated by lines of different lengths. An increase in the length of the arrow reflects a greater degree of influence, with positive correlations in clustering related to leaf length, leaf width, stem base, total height, leaf tip shape, main stem development, crown length, number of

branches, leaf base shape, number of twigs, stem surface texture, leaf vein corners, stem circumference, branch-free height, and crown height. Conversely, negative correlations

in clustering are related to crown density, number of leaves, bark thickness, petiole length, and inner stem color.

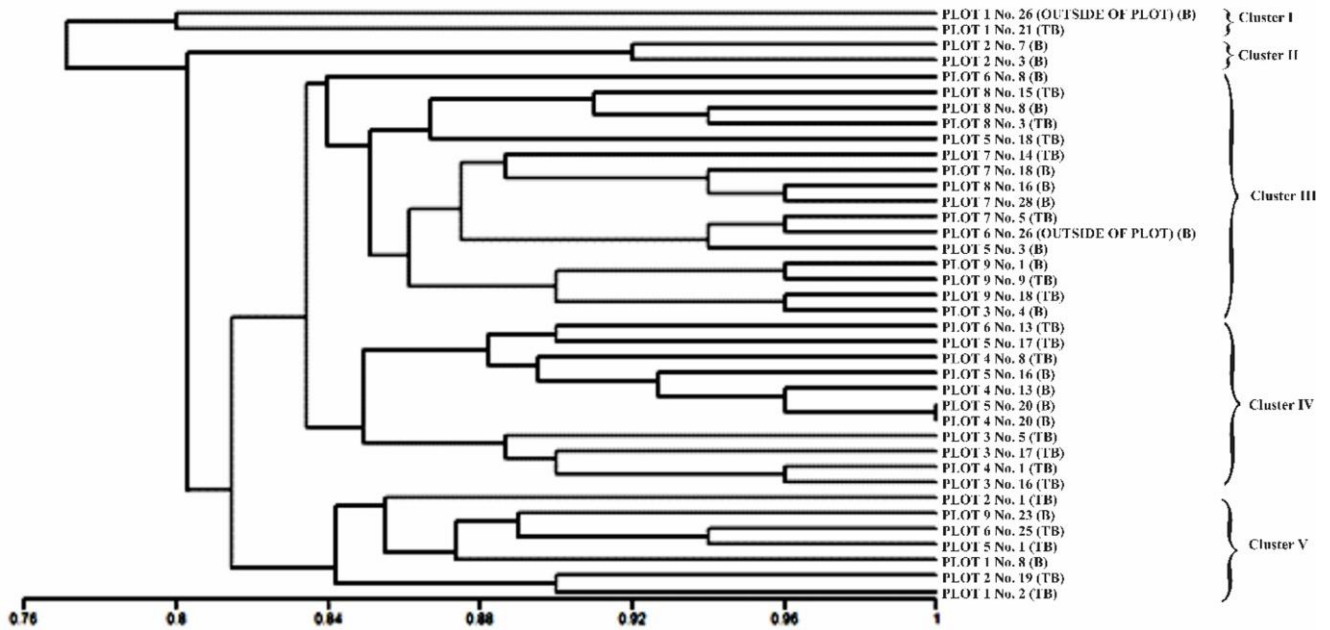


Figure 4. Morphological characters phenogram of CSO Padangan, Cepu, East Java, Indonesia. Note: B: Mistletoe; TB: Without mistletoe

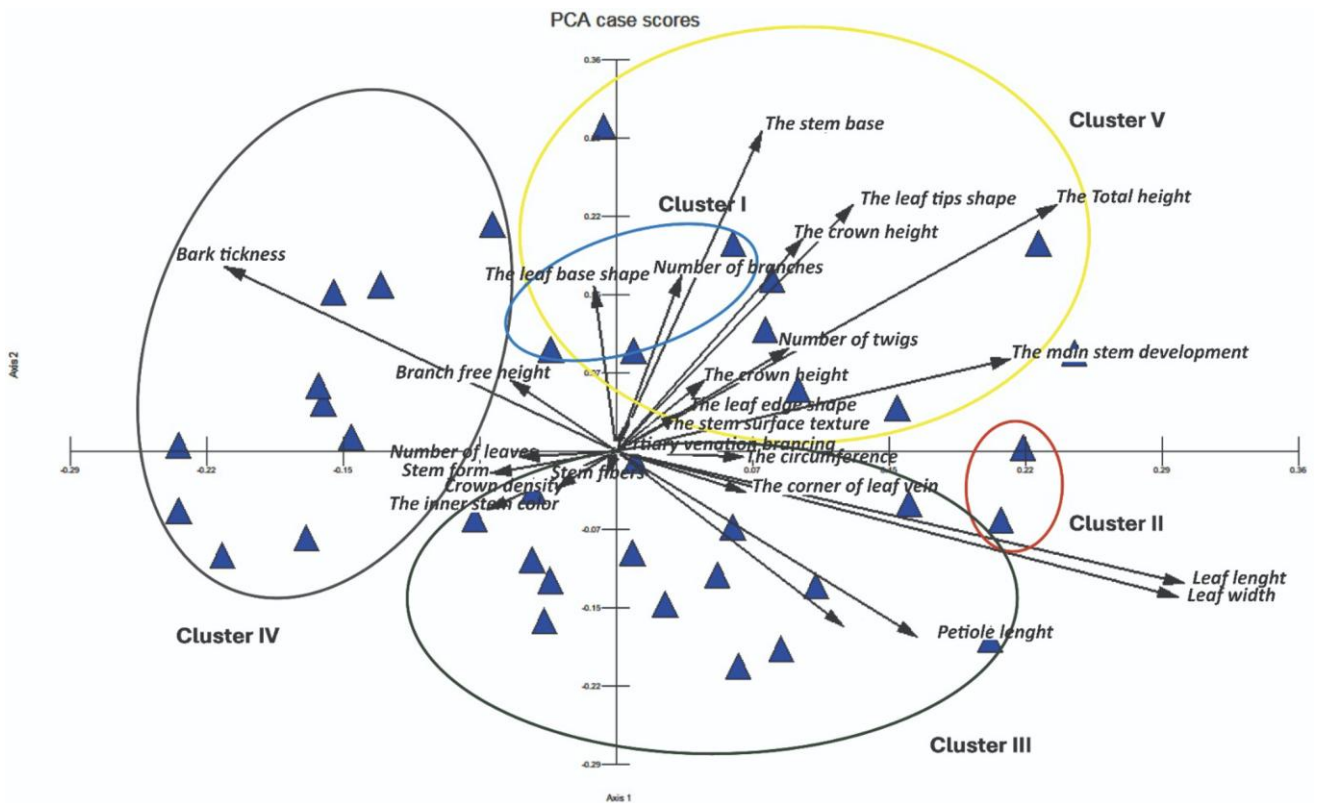


Figure 5. Scatter PCA case scores of CSO Padangan, Cepu, East Java, Indonesia

**Table 1.** Description of clone teak's morphological characters in three sites in Perhutani, East Java, Indonesia

Morphological character	Clonal Seed Orchard (CSO) plot		Jati Plus Perhutani (JPP) plot		Seed Production Stand (SPS) plot	
	TB	B	TB	B	TB	B
The main stem development	simpodial, monopodial	simpodial, monopodial	monopodial	monopodial	monopodial	monopodial
The stem base	deep grooved, long; shallow grooved, short	deep grooved, short; shallow grooved, short	shallow and twisted grooved; deep grooved; slightly buttress	shallow grooved, twisted grooves, deep grooved	shallow grooved, slanted groove	shallow grooved, grooved a little
The stem surface texture	slightly rough-rough peel	smooth-rough peel	smooth-rough peel	smooth-rough peel, not peel	smooth-rough peel	smooth-rough peel, not peeling
Stem form	slightly straight, straight	slightly straight, straight, two- pronged	straight, slightly straight, slightly bent; many branches	slightly straight, straight, a bit crooked, crooked; branches	slightly straight, straight, a bit crooked, big-branches	slightly straight- straight stem, slightly bent
The circumference (cm)		151.15±37.19		74.49±21.87		68.11±23.24
The outer bark color	light brown-grayish	light brown-grayish	gray	gray	gray	gray
The inner bark color	brown	Brown	brown	brown	brownish yellow	brownish yellow
The inner stem color	whitish yellow, yellow, yellowish white, pale yellow	pale yellow, yellow	pale yellow, yellow, yellowish white	yellow, pale yellow, yellowish white	pale yellow, yellow	yellow, pale yellow
Stem fibers	straight, wavy	Straight	straight	straight	straight	straight
Petiole length (cm)		1.73±1.20		0.69±0.59		1.72±1.91
Leaf flesh	slightly thin, thin, moderate	slightly thin, thin, moderate	slightly thin, thin, moderate	slightly thin, thin, thick	slightly thin, thin, thick	slightly thin, thin, moderate
The Leaf tips shape	tapered-rounded, tapered-pointed, pointed, rounded	pointed, rounded, pointed- rounded, pointed slightly rounded, pointed tapering	tapered pointed, pointed rounded, pointed slightly rounded	tapered, pointed, rounded pointed, pointed, slightly rounded, slightly rounded	pointed slightly rounded	pointed, slightly rounded, rounded
The leaf base shape	tapered-rounded, tapered, pointed	tapered, pointed, tapered rounded, tapered pointed	tapered, tapered pointed	tapered	tapered, pointed	tapered
The leaf edge shape	flat-wavy, flat	flat	flat	flat	flat	flat
Leaf symmetrically	symmetrical, somewhat symmetrical, asymmetrical	symmetrical, somewhat symmetrical, asymmetrical	symmetrical, asymmetrical	symmetrical, asymmetrical	symmetrical, asymmetrical	symmetrical, asymmetrical
The upper leaf surface	smooth, slightly hairy	smooth, slightly hairy	smooth, slippery, somewhat smooth a bit rough, rude	rather rough, rough, smooth	smooth, somewhat smooth, a bit rough, rude	smooth, slightly rough, rough
Crown density	rare, moderate, dense	very rare, rare, moderate, dense	rare, moderate, dense	very rare, rare, moderate	rare, moderate, dense	rare, moderate
Leaf length (cm)		29.60±8.56		31.52±9.53		29.55±8.18
Leaf width (cm)		16.65±4.95		16.14±6.73		16.01±5.32
The corner of leaf vein (°)		46.03±5.71		46.93±10.89		48.31±10.76
Bark thickness (cm)		0.28±0.11		0.26±0.07		0.30±0.08
The total height (cm)		19.21±4.94		14.24±3.68		11.93±1.33
Branch free height (cm)		4.96±3.53		3.72±2.61		5.25±1.01
The crown height (cm)		6.68±3.31		4.03±1.17		3.29±0.47
The crown width (cm)		10.16±4.62		5.48±1.54		4.29±0.61
Crown density	rare, moderate, dense	very rare, rare, moderate, dense	rare, moderate, dense	very rare, rare, moderate	rare, moderate, dense	rare, moderate
Number of branches		10.71±5.45		12.18±5.70		8.79±3.21
Number of twigs		11.84±6.15		6.20±1.87		5.86±0.77
Number of leaves		199.26±102.38		80.08±47.28		93.93±39.86

*Phenogram of Jati Plus Perhutani (JPP)'s morphological characters*

The results of morphological character analysis, phenogram of the JPP plots, are described in Figure 6. Morphological observations of 20 pairs of JPP samples are divided into 2 categories: Category A and Category B. The letter A in the sample number indicates healthy teak, while the letter B indicates teak affected by mistletoe. Of the total 40 samples, 20 JPP samples were paired with 20 teak samples derived from seeds of CSO Padangan; they are divided into 2 clusters in the JPP phenogram tree. The JPP phenogram tree has an SIV ranging 0.81-0.83 (81.0-83.0%), indicating a high level of similarity, whereas dissimilarity values fall within the range of 2.1% to 20.1%.

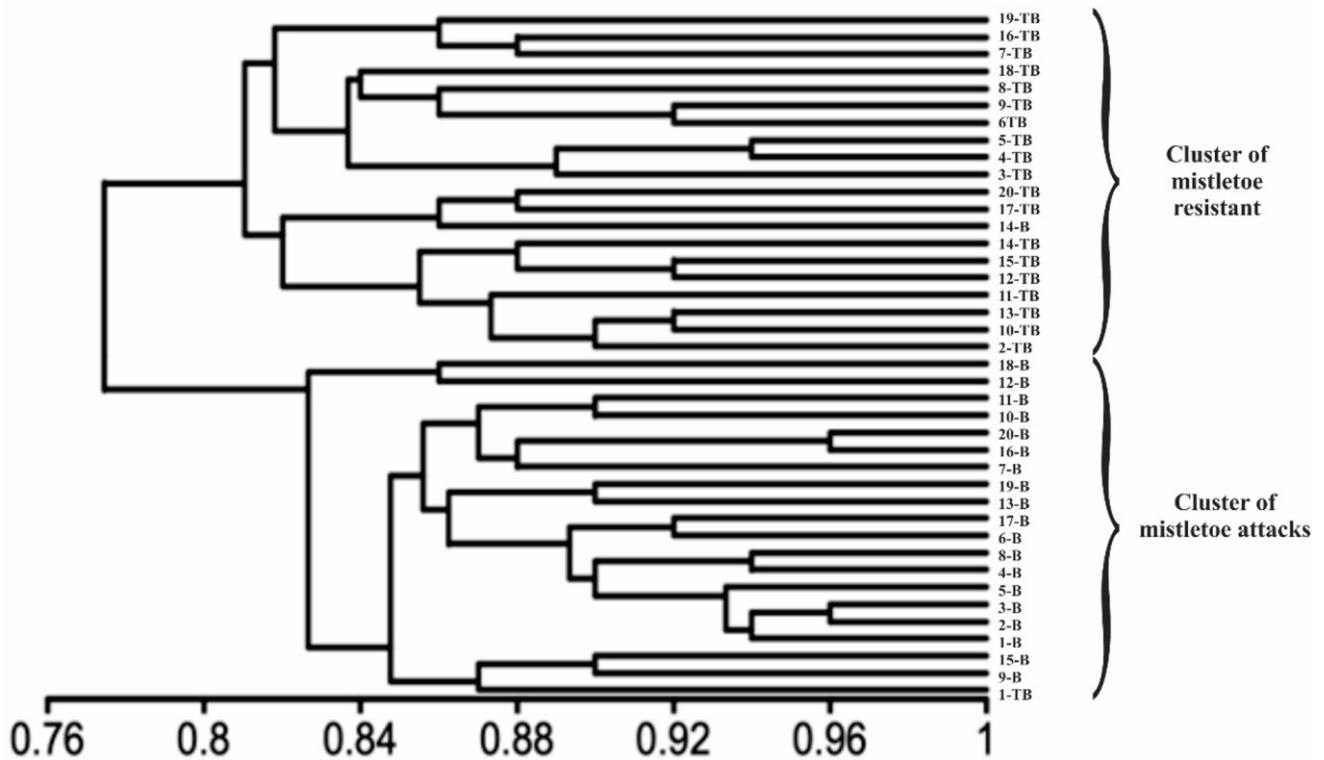
Cluster I consists of 20 JPP samples with an SIV of 0.81. This indicates that their character similarity values are nearly identical. Almost all the trees in cluster I are healthy and free from mistletoe infestation, with only one infected tree. The teak clones in this cluster demonstrate advantages over other teak trees, as healthy trees (without mistletoe) are grouped. Cluster II consists of 20 JPP samples with an SIV of 0.83. This cluster contains only 1 healthy teak clone and 19 teak trees affected by mistletoe. Notably, the pair of samples 1-A and 1-B are in one cluster of mistletoe attacks, indicating that there is no strong distinction between healthy teak samples and those affected by mistletoe.

Generally, the degree of morphological similarity affects the degree of kinship. Variations in similarity or dissimilarity arise from differences in plant morphology, including qualitative and quantitative characters. These

characters are not random, but are regulated by a complex interplay of genetics and the environment. To maximize their genetic potential, plants require particular environmental conditions (Handayani and Ismadi 2018). This understanding of the role of genetics and the environment in shaping plant morphology is crucial. It may underpin future strategies for development and preservation (Sari et al. 2024) and tree improvement. The scatter PCA case scores for the JPP plot are presented in Figure 6. In PCA (Figure 7), longer arrow lines indicate greater influence, with positive correlations in clustering related to stem circumference, crown density, number of branches, number of leaves, total height, crown width, crown length, leaf length, base of stem, petiole length, and inner stem color. Conversely, negative correlations in clustering are associated with branch-free height and bark thickness.

*Phenogram of the stand of seed production area morphological characters*

The results of the morphological character analysis phenogram of the SPS plot are described in Figure 8. Figure 8 shows the results of morphological assessments conducted on seven pairs of SPS teak clones across three different plots. Of the total 14 teak tree samples, SPS is divided into two clusters. The phenogram of kinship trees has an SIV ranging from 0.84 to 0.86 (84.0-86.0%), indicating a high level of similarity, whereas the level of dissimilarity is between 14.2% and 16.5%.



**Figure 6.** Morphological characters phenogram of Jati Plus Perhutani's plot in Perhutani, East Java, Indonesia. Notes: A: Without mistletoe, B: With mistletoe

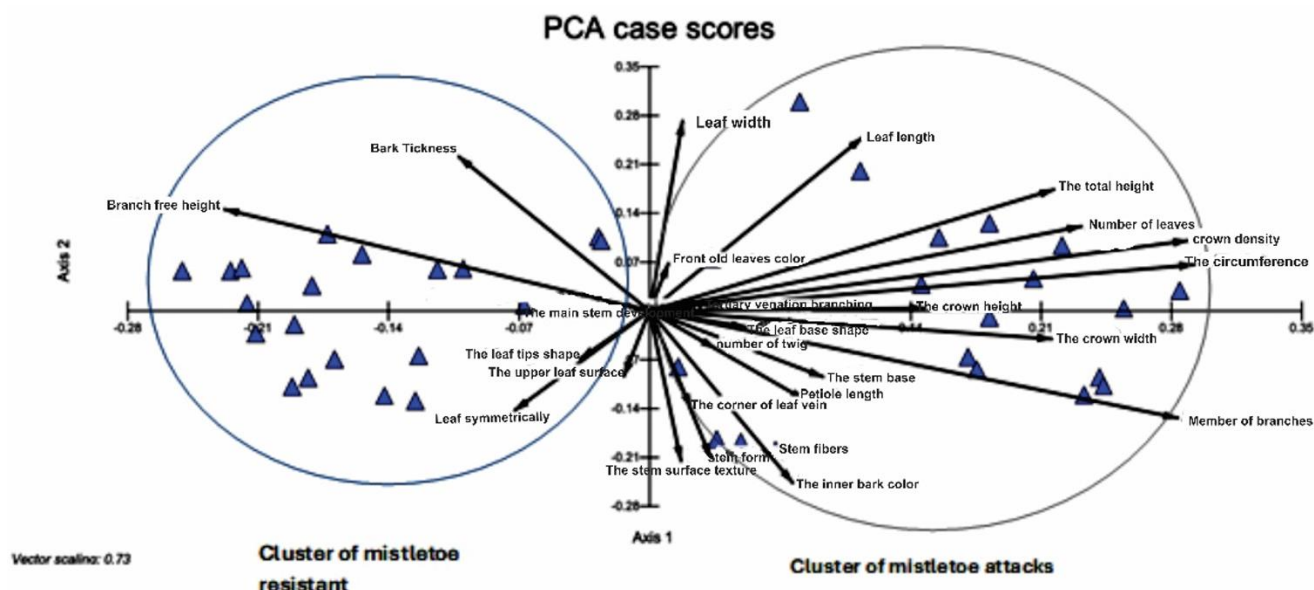


Figure 7. Scatter PCA case scores of the JPP plot in Perhutani, East Java, Indonesia

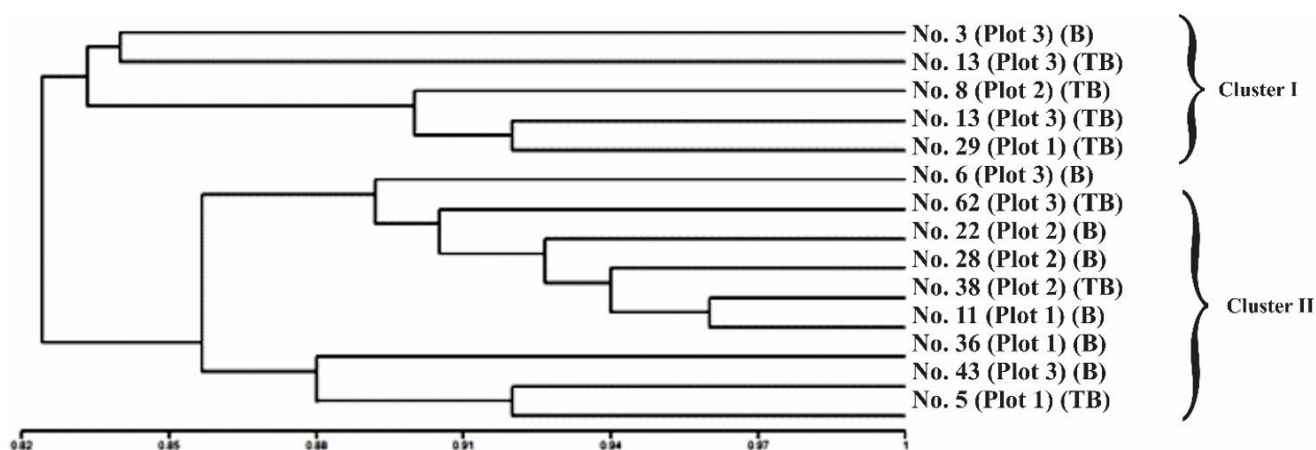


Figure 8. Morphological characters phenogram of the Seed Production Stand (SPS) plot. Notes: B: Mistletoe. TB: Without mistletoe

Cluster I consists of five teak tree samples. The same sample trees in different plots can be grouped into the same cluster within a given site. This cluster is dominated by teak trees without mistletoe, with only one tree exhibiting mistletoe infestation, and a similarity index value of 0.84. In other words, the teak trees without mistletoe share relatively similar morphological characters and are grouped in one cluster. Cluster II consists of nine teak tree samples with an SIV of 0.86. This cluster contains six mistletoe-affected trees and three healthy trees. Several factors contribute to the lack of significant differences between healthy trees and those affected by mistletoe, including weather conditions, the age of the trees, and the presence of other diseases.

The scatter PCA case scores for SPS are shown in Figure 9. In PCA (Figure 9), longer arrow lines indicate greater influence, with positive correlations in clustering

related to leaf vein corners, leaf base shape, stem form, number of leaves, crown density, number of branches, leaf tip shape, base of stem, and petiole length. Conversely, negative correlations in clustering are associated with leaf length, upper surface of the leaf, bark thickness, leaf width, leaf flesh, inner stem color, and stem circumference.

**Correlation of positive and negative morphological descriptors**

Overall, the morphological characters demonstrate that the clustering of teak clones and teak from seed clones is influenced by their endurance to mistletoe across the three sites or three populations, with 21 characters exhibiting positive correlations, namely leaf length, leaf width, base of stem groove, total height, leaf tip shape, main stem development, crown length, number of branches, leaf base shape, number of twigs, stem surface texture, leaf vein

corners, stem circumference, branch-free height, crown height, crown density, number of leaves, crown width, petiole length, inner stem color, and stem form. When sorted based on the greatest positive correlation value of  $R-PCn > 3.50$ , the sequences of 10 characters are leaf vein corners, leaf base shape, leaf length, leaf width, base of stem groove, number of leaves, stem circumference, crown density, number of branches, and total height. Of 10 characters significantly with 8 of quantitative of positive correlations, namely leaf vein corners, leaf length, leaf width, number of leaves, stem circumference, crown density, number of branches and total height, along with 2 qualitative traits, namely base of stem groove, leaf base shape.

Moreover, the clustering analysis indicates 11 characters with negative correlations: crown density, number of leaves, bark thickness, petiole length, inner stem color, branch-free height, leaf length, upper surface of the leaf, leaf width, leaf flesh, and stem circumference. Notably, some characters (8 in total) exhibit both positive and negative correlations: crown density, number of leaves, petiole length, inner stem color, branch-free height, leaf length, inner stem color, and stem circumference.

As it has been explained, this study also identified several quantitative traits with negative correlations, namely crown density, number of leaves, bark thickness, petiole length, branch-free height, leaf length, leaf width, and stem circumference (8 characters), alongside qualitative traits, namely inner stem color, upper surface of the leaf, and leaf flesh (3 characters). These results, in line

with Maruzy and Susandarini (2024), suggest that the phenotypic differences observed among *C. asiatica* accessions have a genetic foundation. It was strengthened by Lázaro-González et al. (2021), even though the trees' host changes in morphological and reproductive traits due to parasitism have been well concluded by other studies. Similarly, Asih et al. (2022) indicated that characteristic variations may result from genetic factors due to plant adaptation to different environmental conditions. Furthermore, Modi et al. (2018) found significant variation in morphological parameters such as height, diameter at breast height, then leaf length, leaf width in teak clones. Morphological characteristics of teak clones can vary, and this variation may be influenced by genetic factors, environmental factors, and phenotypic plasticity, namely the ability of the same genotype to produce different phenotypes in response to environmental changes (Reategui-Betancourt et al. 2020).

The result of the other relevant study by Wang et al. (2023) was that leaf morphological traits differed greatly among the host tree species, but it did not find differences in those traits (i.e., single leaf area, single leaf mass, and LMA) of *Viscus album* ssp. *album* across the mistletoe-host pairs and some sites differing in environmental conditions. This result was surprising since a controlled experiment conducted in a long-term irrigation forest showed that *V. album* ssp. *austriacum*, another subspecies of *V. album*, had larger leaves and a lower LMA than mistletoe growing in wetter conditions.

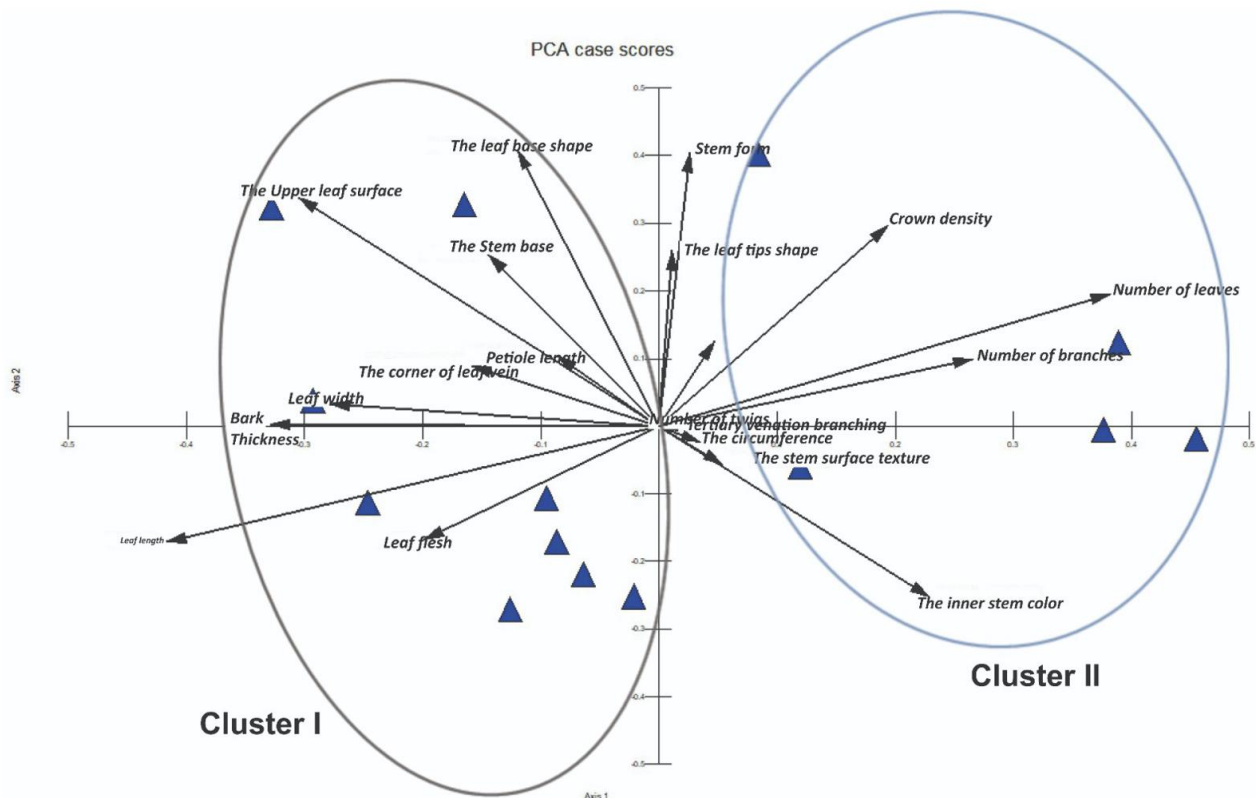


Figure 9. Scatter PCA case scores of the SPS plot

In comparison to other studies, Solikin (2024) reported that the character of stem circumference is correlated with mistletoe infestation; as the diameter of *Falcataria moluccana* infested with mistletoe increases, the number of mistletoe infestations also increases. Conversely, a reduction in diameter corresponds to a decrease in the infestation of mistletoe. In their study, Sreekanth et al. (2013) analyzed nine natural populations in the Western Ghats of Southern India by using AFLP markers and evaluating 11 morphological traits, including GBH, tree and bole heights, branch knot number, fluting presence, stem spirality, leaf hair, leaf length/breadth ratio, branching type, bark color, and petiole morphology.

Reategui-Betancourt et al. (2020, 2021) identified 17 morphological characters showing consistent performance at 29 and 41 months of age in teak clones in plantations in Brazil. Therefore, it is suggested that these 17 characters, which exhibit distinguishability, homogeneity, and stability (DHS), remain stable at those ages and serve as morphological descriptors for 30, 60, 90, and 120-day-old cuttings. Traits such as leaf blade length, width, length/width ratio, green intensity, and leaf brightness exhibited different levels of expression. A total of 24 characters based on leaf and stem morphology were studied in 30 teak sources. Vishnu et al. (2022) characterized morphological descriptors of 30 seed sources of teak across 11 different states in India. They reported significant differences among 17 characters, namely leaf length, leaf width, petiole presence and length, leaf base shape, leaf texture, leaf attitude, leaf margin undulation, leaf brightness, leaf venation, leaf vein color, leaf color, leaf pubescence, young leaf color, number of internodes, internodal length, and trunk color. These findings may provide useful preliminary information for formulating characterization descriptors for genetic improvement programs.

Alcântara et al. (2016) collected samples of teak clones from various provenances, including Caceres (Brazil), Solomon Islands, Indonesia (Cepu), and Thailand. Their results highlighted that leaf length and width could differentiate teak provenances from the Solomon Islands, Indonesia, and Thailand. Inflorescence length also varied, with the Indonesian provenance differing from the Solomon Islands and Caceres, but resembling that of Thailand. Additionally, ovary size in the Caceres provenance differed from both the Solomon Islands and Indonesia. Thus, regarding quantitative traits, the Caceres provenance was more similar to the Indonesia provenance in terms of leaf length, leaf width, petiole length, inflorescence width, fillet and anther lengths, calyx lobe and corolla lobe lengths, and number of sepals and petals. Larekeng et al. (2019) reported that morphological analysis of provenance in Cepu, Sidrap, and Bau-Bau categorized leaf color into five groups: green-brownish, green-yellowish, green, dark green, and green with yellow spots. Most leaf shapes were wide ellipses, except for those in Bau-Bau provenance, which exhibited inverted oval shapes. All observed leaf samples had flat margins, tapered tips and bases, rough textures, and pinnate venation. Tree height and diameter were greater in the Bau-Bau

provenance compared to those in other provenances. Prasetyawati and A'ida (2019) studied provenance samples from Malabar, Muna, Java, in Ngawi Regency and Padangan District. They concluded that the Malabar provenance exhibited the largest differences in both macroscopic and microscopic morphology, with cluster analysis indicating its similarity coefficient was the lowest among all provenances.

Morphological characters associated with resistance to mistletoe are generally those showing a positive correlation with host tolerance, whereas characters negatively correlated are linked to susceptibility. For example, a higher branch-free bole height provides more opportunities for birds to perch, thereby increasing the likelihood of mistletoe colonization. This observation contrasts with the findings of Muhammad et al. (2022), who reported that mistletoe occurrence is not significantly influenced by host attributes such as tree height, crown size, or basal diameter.

In the present study, trees with longer or larger leaves tended to show higher levels of mistletoe infestation, although the relationship was not strictly linear. A denser or taller teak canopy was also associated with increased mistletoe prevalence. The relationship between larger leaf area and higher infestation aligns with previous findings, which indicate that mistletoe genetic diversity is greatest in the upper crown, suggesting that trees with broader canopies and larger leaves may be more vulnerable (Muttaqin et al. 2020). Furthermore, host trees with thinner and smoother bark were more susceptible to mistletoe attachment, as these conditions facilitate the penetration of haustoria. Haustorium formation involves the development of specialized parasitic roots that mechanically invade the host's bark or wood, a process known as the primary haustorium stage (Hu et al. 2017; Dołkin-Lewko et al. 2025). These haustoria continue to grow until they establish connections with the host's vascular tissues, specifically the xylem, which transports water and minerals, and phloem, which translocate photosynthates (Wang et al. 2023; Zhang et al. 2023). Once established, haustoria extract essential resources from the host (Muche et al. 2022) while also serving as firm anchorage structures that secure the mistletoe to its host branch (Thomas et al. 2023).

For further this study will be done about the advanced selection of teak clones resistant to mistletoe through molecular markers, as a complement to the results based on morphological traits. Hopefully, later, it will be known whether the morphological appearance is a teak clone that is potentially resistant to mistletoe due to genetic factors or as an adaptation to the current uncertain environmental changes.

#### *Environmental factors*

Mistletoes have a harm effect on associated hosts. As a consequence of the competition for host resources, the host diminishes growth and vigor, decreases the quality and quantity of wood, and heightens the susceptibility to attack by other pathogens (Muche et al. 2022), like various pests and disease of plant. Besides that, the growth of mistletoe

as plants are surrounded by an enormous number of biotic and abiotic stressors (Klutsch and Erbilgin 2018).

According to Li et al. (2018), the study of plant variation across diverse environments is essential for understanding genetic diversity, genetic breeding, and the foundations of conservation biology. Environmental factors influencing the variation in the morphological characters of teak trees at the three research sites involve several aspects related to the interaction between mistletoe and its host, as well as the surrounding environmental conditions, including temperature, rainfall, humidity, and environmental light conditions (light and shade). Especially, the crown density character influences light intensity and the shading underneath the crown of the tree. This is also consistent with the findings of Larekeng et al. (2019), who conducted morphophysiological analyses of teak from three provenances and reported that tree diameter and height were primarily influenced by soil nutrient content, soil moisture, and sunlight. One key environmental factor affecting tree character (diameter) is the quality of the growing site. The growing environment plays a significant role in variations in growth and wood formation. Favorable conditions promote rapid tree growth, whereas nutrient deficiencies and low humidity lead to slower growth. Data on these environmental factors at the three locations are presented in Table 2.

Mistletoe requires an optimal temperature range of 20°C-30°C; within this range, it efficiently absorbs nutrients from the host because the host's metabolism functions optimally. The temperatures at the three locations are considerably high, with the JPP plot reaching 39.8°C. Excessively high temperatures, particularly above 35°C, can result in heat stress in the host plants, thereby adversely affecting the mistletoe's nutrient acquisition. This temperature stress not only impairs the mistletoe's ability to thrive but also may lead to dehydration or a decrease in the host's photosynthetic capacity, posing a threat to the overall health of the host plants. Some studies indicate that high temperatures reduce the growth efficiency of plant parasites, including mistletoe (Padfield et al. 2019). Earlier research on seed germination also suggests that the temperature and light conditions at the study site may influence mistletoe seed germination (Luo et al. 2016).

Humidity is another critical environmental factor affecting mistletoe growth. It affects physiological processes, transpiration, and water absorption in both the mistletoe and its host. The humidity at the research locations is relatively low (<60%). Martinez and Merino (2011) stated that low humidity conditions increase the transpiration ability of the host plant, potentially leading to water shortages. When the host plant experiences water stress, the mistletoe also struggles to obtain sufficient nutrients and water, thereby hindering its growth. Thus, it is unsurprising that mistletoe is widely recognized for its adverse effects on the host, such as the evocation of reduced needle size and reproductive capacity in pine, which in turn leads to reduced secondary growth and even contributes to tree mortality. In this context, mistletoe has been discussed as a predisposing factor for increased pine

mortality during drought stress (Yan et al. 2016). Nevertheless, comparative eco-physiological studies at site variation with different environmental conditions were relatively rarely (Richards et al. 2021).

Light intensity and shade are also important factors affecting mistletoe growth because mistletoe is highly dependent on photosynthesis for its growth, in addition to obtaining nutrients from its host. Light intensity measurements from the three research locations ranged from 250-1350 lux. Under low light intensity conditions (100-500 lux), mistletoe growth slows because of limited photosynthesis, making the plant more dependent on its host for nutrients. By contrast, under medium to high light intensity conditions, mistletoe is able to photosynthesize effectively (Cameron et al. 2008). The availability of host trees influences the geographical propagation of mistletoe, adequate light conditions, the abundance of dispersal vectors, and, to a significant extent, changes in human land use patterns (Kollas et al. 2017). Solikin (2020) also emphasized that light is essential for mistletoe to perform photosynthesis and produce carbohydrates required for the plant's growth and development.

Shading intensity measurements from the three locations revealed shading intensities of 79.5% for CSO Padangan plot, 62.5% for the JPP plot, and 64.5% for the SPS plot. A shading intensity value exceeding 50% indicates that most sunlight is blocked by the tree canopy, resulting in minimal sunlight reaching the ground surface. Suryanto et al. (2005) stated that increased shading intensity reduces the light reaching the ground. The shading intensity values suggest competition among plants for sunlight. This is the reason for the differences in teak tree growth at each study location. According to Mellado and Zamora (2016), due to its documented exponential growth, the harvested mistletoe population served as a basis for conducting rough estimations of its population dynamics. This function served as external input to the model, as the population dynamics could not be predicted or simulated eco-physiologically (unlike the trees) because the site-specific expansion is highly dependent on local factors such as mistletoe density, influenced by shading intensity and the preferences of dispersing vectors such as *Turdus viscivorus*, *Cyanistes caeruleus*, and *Sylvia atricapilla*. Solikin (2020) also reported that the highest infestation of mistletoe *D. pentandra* on *C. fistula* occurred in an open canopy at Purwodadi Botanic Garden, Pasuruan, East Java, indicating that this species requires ample light for seed germination and growth.

**Table 2.** Environmental factors in three research locations

Environmental factors	Location		
	CSO Padangan	JPP Plot	Seed Production Stand (SPS)
Temperature (°C)	33.2±1.7	35.1±2.0	37.2±1.6
Humidity (%RH)	52±5	46±6	44±6
Light intensity (lux)	890±441	944±212	1009±175
Shade intensity (%)	51±14	52±11	50±10

In conclusion, overall, the teak trees formed a cluster, indicating that those without mistletoe exhibited different morphological characteristics compared to those with mistletoe, particularly in the JPP plot. Finally summarized, there were 5 morphological characters showed significant positive correlations, namely number of branches, total height, the leaf base shape, the base of stem groove and of 6 morphological characters showed negative correlations, namely branch free height, petiole length, bark thickness, inner stem color, upper surface of the leaf, leaf flesh. Both positive and negative correlation character can serve as descriptors for identifying genotypes, aiding in the evaluation of new teak clones (varieties) resistant to mistletoe infestation, a condition where mistletoe plants grow on and parasitize the teak trees, affecting their growth and health. Recommended furthermore, to find the teak clone resistant to mistletoe infestation will do multiplication superior shoots of it through tissue culture techniques. It will take from teak clone samples in JPP site as this research objects. Also, it will be needed to test similarity some morphology characters significantly from the result of this study compare with of them of plants of tissue culture. the time later, those plants will be used as plants stock that resistant of mistletoe for planting broad scale area.

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